



Trouble in Paradise

Goals: To have students use information provided in this activity and what they have learned about groundwater movement in previous activities to determine the source of well contamination in the mythical town of Paradise. To allow students to consider the implications of water contamination and suggest solutions for Paradise's problem.

Subjects: Science, Health, Social Studies, Home Economics, Environmental Science

DPI Objectives: SC: A1-A3, B2, B3, B5, C3, C4, D1-D5

EH: A3, A4, B1, B2, B4, C1-C6

SS: A1, B2, B3, C1, D2, D3

Grades: 7-9 (and up)

Materials:

- ❖ Trouble in Paradise handout
- ❖ colored pencils—red, blue and green

Background: In this activity, wells in the mythical town of Paradise have been contaminated with *volatile organic compounds* (VOC's). VOC's are a group of commonly used chemicals that evaporate, or "volatilize" when exposed to air. Since they dissolve many other substances, VOC's are widely used as cleaning and liquifying agents in fuels, degreasers, solvents, cosmetics, polishes, drugs and dry cleaning solutions. VOC's are found at airports and service stations; machine, print and paint shops; electronics and chemical plants; dry cleaning establishments; and in household products. Two common VOC's, toluene and benzene, are referred to in this activity.

When VOC's are spilled or dumped, some will evaporate and some will soak into the ground. Once in the soil, VOC's can be carried deeper into the ground by percolating rainwater. If they reach the water table, VOC's can persist for years because the cool, dark, low-bacteria environment does not promote decomposition. If VOC's in groundwater migrate to nearby wells, they can end up in someone's drinking water.

Of 2,230 community wells sampled in Wisconsin between 1985 and 1988, 113 (5.1%) have shown the presence of at least one VOC. Some had only traces, one or two parts per billion. But 28

community wells exceeded State Health Advisory Levels for drinking water.

Some VOC's can harm the central nervous system, liver and kidney. For these types of health effects, researchers can determine a "no-effect level"—a maximum VOC dose that does not produce the toxic effect in experiments. This "no-effect level" is further reduced by a safety factor which ranges from one tenth to one thousandth (depending on the strength of scientific evidence). From this number State Health Advisory Levels and EPA Maximum Contaminant Levels are established. Some VOC's (such as benzene) are known or suspected carcinogens (cancer-causers). Health Advisory Levels and Maximum Contaminant Levels for carcinogens in drinking water are conservatively set so that lifetime consumption of the water will cause no more than 1 to 10 additional cancers for every million persons exposed.

Several factors influence a well's vulnerability to VOC contamination. One factor is the distance between the well and the source or sources of contamination. Another factor is time. Groundwater usually moves very slowly and it can sometimes take years for a spilled contaminant to reach nearby wells. The time and distance contaminants must travel are extremely important because many wells which presently show no contamination may eventually become contaminated by spills that have already occurred. In other words, we may not know the full effects of contamination we already have caused for many years to come. (see *Groundwater Supplement* pg. 17)

There are two options for dealing with VOC contamination. The well owner can either construct a new well or treat water from the contaminated one. Treatment of the well water has the benefit of removing contaminated water from the ground. Both options are expensive. Drilling a new municipal well can cost as much as \$500,000; building a water treatment facility for a contaminated municipal well generally costs between \$500,000 and \$1 million.

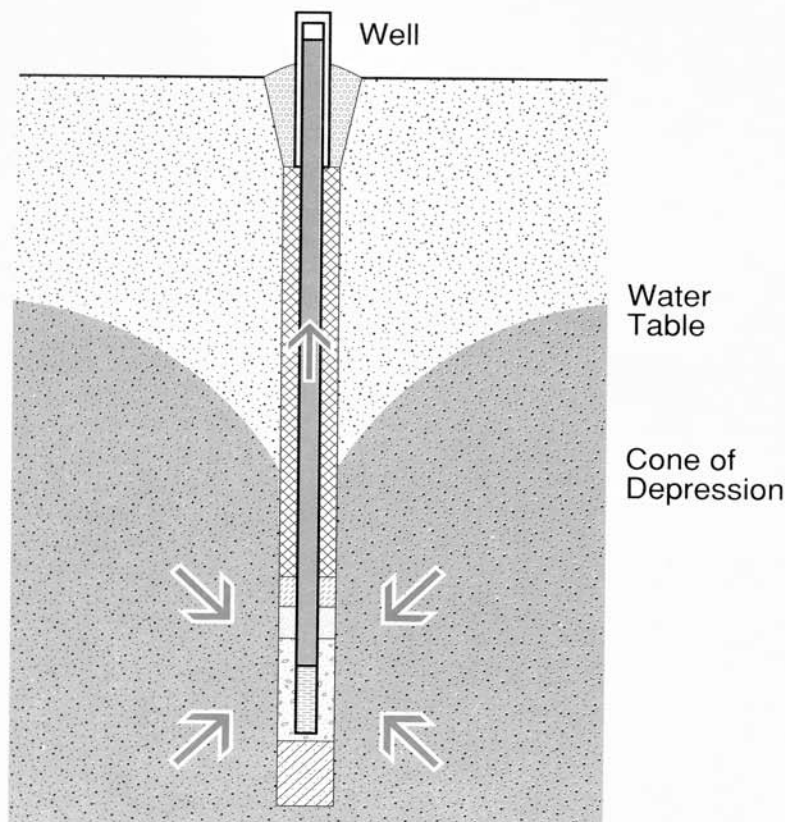
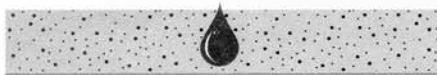
Activity setting:

VOC contamination has occurred in "Paradise" and your students will be asked to determine where the VOC's came from and what should be done about the problem. The contamination was first noticed after the installation of a high capacity community well. Wells that draw a large volume of water can affect the direction and rate of groundwater flow by creating a "cone of depression." As groundwater is depleted under the well site, it is replaced by groundwater from soils surrounding the well. So even water that initially flowed away from the well can be drawn toward it as groundwater immediately under the well is removed.

The new municipal well in "Paradise" has created a cone of depression and is drawing water and the plume of VOC contamination toward itself. The source of contamination is the closed landfill at the Johnson farmsite which, while it operated, may have accepted wastes containing VOC's from local industries and households. This landfill was designed as a "natural attenuation" site, meaning that the landfill depended only on the characteristics of surrounding soils to contain and filter leachate from the waste deposited there. Today landfills must be lined with a layer of impermeable clay which helps to contain leachate. Modern waste disposal regulations also limit the type of wastes that can be deposited in a municipal landfill.

Procedure:

1. Using How Much is a Part per Billion? handout, discuss the idea of parts per billion, parts per million and parts per thousand. Explain that drinking water standards are often stated in parts per billion and that laboratory results are usually stated in ug/L. Point out that 1 ppb = 1 ug/L.
2. Tell students that the mythical town they will be investigating is based on several Wisconsin communities that actually experienced groundwater contamination. Explain what VOC's are and their many sources. Briefly discuss how Health Advisory Levels and Maximum Contaminant Levels are set.



3. Distribute "Trouble in Paradise" handouts. Have students read the case study.

4. Ask individual students to read aloud the problems on the activity sheet. Clarify any uncertainties about the problems.

5. Working in small groups, complete the activity sheet. Remind students that they will need to use the information given in the case study AND what they have learned in previous activities to answer the questions. It may be helpful to review the reading of topographic maps.

6. Using the completed worksheets, construct a master time line on the chalkboard. Discuss the time line and answers to activity sheet questions.

- ❖ In what general direction does groundwater flow in Paradise?
- ❖ What is the source of contamination? How do you know?
- ❖ Where would you place test wells to confirm the source of contamination?

❖ What is a plume of contamination?

❖ How did the shape of the plume of VOC contamination change? What caused it to change?

❖ Why did it take so long for the VOC's to move from their source into surrounding wells?

❖ Why did the contamination appear in the Hansens' well then seem to disappear?

❖ Why was there such a delay between the time that VOC's were first discovered in the Hansen's well and when city officials decided to take action?

6. Discuss the implications of groundwater contamination in Paradise.

- ❖ What are VOC's used for?
- ❖ Who might have put materials containing VOC's in the landfill?
- ❖ When is groundwater "contaminated?" Is water that contains 200 ppb toluene considered contaminated? Is 200 ppb toluene considered unhealthy?

❖ Does contaminated necessarily mean unhealthy?

❖ Why do you think the Health Advisory Level for toluene is so much higher than the Maximum Contaminant Level for benzene?

❖ Who's to blame for the contamination?

❖ Who should pay to solve the problem?

❖ How did the citizens react to the contamination? Were their demands reasonable? What else could citizens do?

❖ How did the contamination affect private well owners?

❖ Should the Smiths' and Thompsons' well water be restored (either by construction of a new well or by treating water from existing wells)? If so, who should pay?

❖ Could the contamination affect the new community well?

❖ How long can Paradise's problem continue?

❖ If hazardous materials are removed from the landfill in Paradise, they may have to be moved to a hazardous waste landfill in another state. Is that fair? Who should pay to maintain and operate the disposal site?

❖ Could the contamination have been avoided? If so, how?

❖ What can Paradise do about the contamination now?

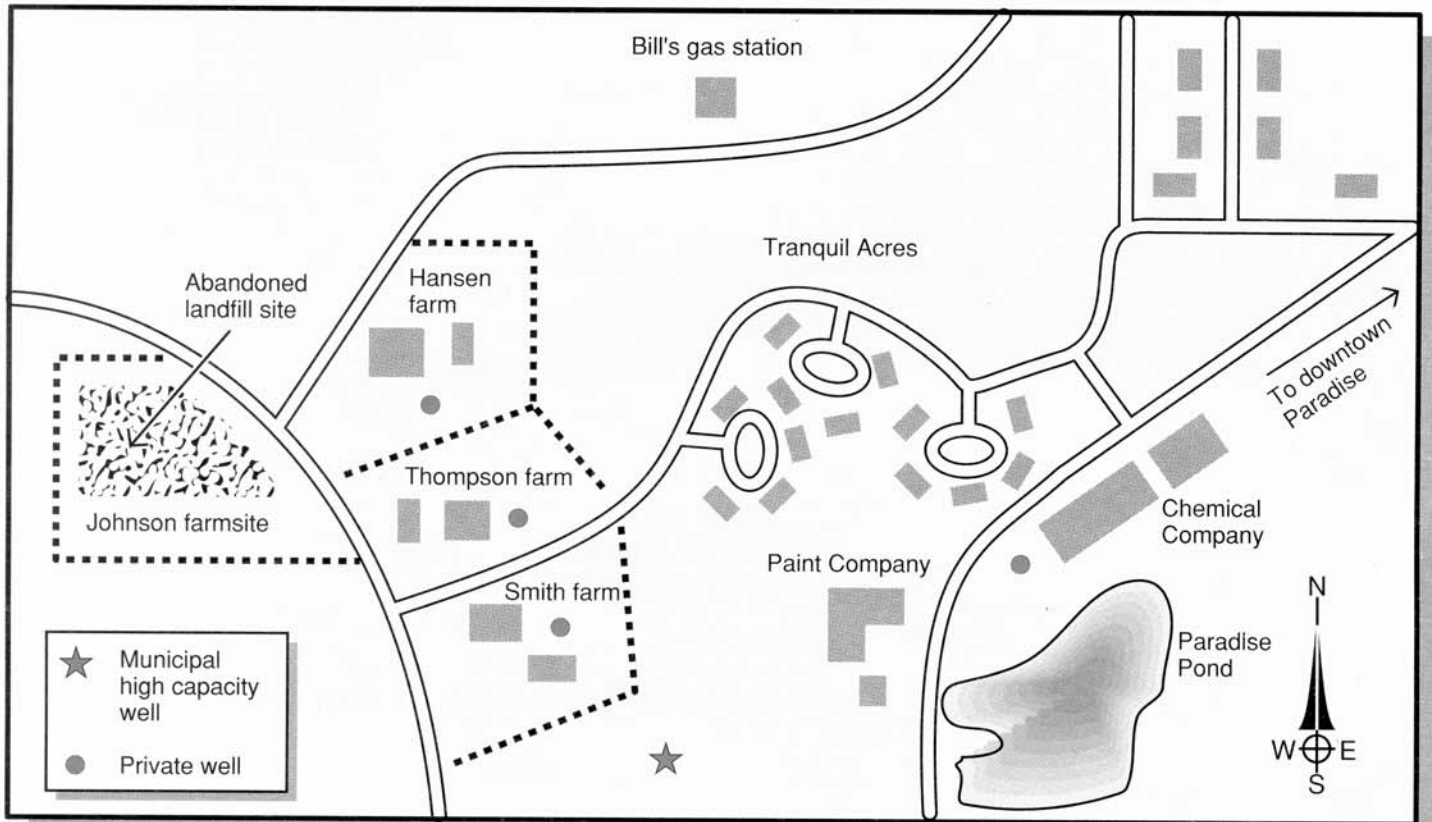
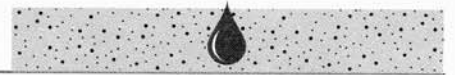
❖ Could your community have problems like this?

❖ How can your community help prevent groundwater contamination problems?

Going Beyond:

1. Using selected discussion questions as an outline, research and report on a groundwater contamination issue in your area.

Adapted from: Discovering Groundwater: A Supplementary Activities Guide for Upper Elementary Social Studies and Science Classes. 1984. Wisconsin Department of Natural Resources, Western District.



Map A





Trouble in Paradise

activity sheet

The mythical town of Paradise is a rural township of about 5,000 people. Most residents run small farms or local services and businesses. The rolling countryside of the township has attracted urban workers in recent years from the nearby city of Crystal Springs and the town is experiencing its first major growth period in 20 years.

A small industrial area lies just west of downtown Paradise. This area includes a paint manufacturing company and a chemical plant. Both of these industries use water in their manufacturing processes and both produce chemical wastes. The paint and chemical companies were built in the late 1940's. In 1950, a municipal landfill was built west of the industrial site. The landfill accepted 500,000 cubic yards of municipal and industrial waste from 1951 until the landfill was covered in 1960.

The landfill site was sold to Jean Johnson for farming in 1962; the farm house was destroyed by fire in 1978, and the land was sold for suburban development in 1979. A gas station was opened near the farm site in 1980.

Through the late 1950's, all Paradise residents drew their drinking water from private wells. As more and more people moved into Paradise, residential neighborhoods expanded to the west and what had been farmland became suburban neighborhoods. In 1963 Paradise incorporated as a city. A new subdivision, Tranquil Acres, was developed between the industrial area and the Johnson farmsite during the early 1980's. Subdivision plans called for one high capacity well to serve the new homes. The well was installed in 1983 and began pumping water in March 1984.

In February 1983, members of the Hansen family began experiencing dizziness and headaches. The Hansen home is one of three remaining farms in Paradise and is located about 1/2 mile west of Tranquil Acres. Their home was built in the early 1900's and has its own private well. The Hansens suspected that their well water was causing their symptoms and in March 1983 they contacted the city health department. The city health department did not have the means to detect many contaminants, so they called in county health officials.

In May 1983, lab samples drawn by the county showed that the Hansens' well contained volatile organic compounds (VOC's), including benzene and toluene. The well samples contained 350 ug/L toluene and 4 ug/L benzene. County health officials advised the Hansen family to use bottled water for drinking and to minimize contact with water by taking shorter, cooler showers, running the exhaust fan during showers, ventilating the bathroom after showering, and opening kitchen windows when running the dishwasher.

VOC	Sources	Health effects	HAL/MCL
Toluene	industrial wastes, dyes, solvents, perfumes, medicines, manufacturing of organic chemicals	irritability, disorientation, liver and kidney damage	* 68.6 ppb
Benzene	leaking gasoline tanks, industrial wastes, solvents for plastics, and paints	death, nausea, headache, unconsciousness, paralysis, CANCER	** 4 ppb
* Wisconsin Health Advisory Level (1989)		** EPA Maximum Contaminant Level (1989)	



Between May 1983 and May 1984, local wells were monitored for VOC's. Each well was tested three times.

Well	June 1983		February 1984		April 1984	
	tol	benz	tol	benz	tol	benz
Hansen's farm	350	4	50	0	0	0
Thompson's farm	70	0	188	1	290	1
Smith's farm	0	0	0	0	0	0
Paint Company	0	0	0	0	0	0
High capacity well	0	0	0	0	0	0
Note: Results are in ug/L. 1 ug/L = 1 ppb.						

The Hansens' well showed high levels of VOC's in June 1983, but only traces of VOC's in February 1984. By April 1984 the contaminants seemed to have disappeared from the Hansen well. In June 1984, the Smith's began to experience the same symptoms that the Hansens had experienced in 1983. The Smiths called the county health department to report the problem. Paradise officials decided a full scale investigation was in order. They feared that the contamination might be drawn toward the new high capacity well in the subdivision.

The area wells were sampled again in May and July 1984 with the following results:

Well	May 1984		July 1984	
	tol	benz	tol	benz
Hansen's farm	0	0	0	0
Thompson's farm	360	2	410	6
Smith's farm	200	0	260	1
Paint Company	30	0	30	0
High capacity well	0	0	0	0
Note: Results are in ug/L. 1 ug/L = 1 ppb.				

Public health officials advised the Thompsons and the Smiths to use bottled drinking water and minimize contact with their well water. In addition to benzene and toluene, water tests revealed that the Thompson's well was also contaminated with methane gas produced by decaying organic material. Methane gas can be carried underneath homes by groundwater where, in high enough concentrations, it can cause explosions.

After hearing the results of the health department tests, residents of Tranquil Acres formed a citizen action group. They feared that the high capacity well was in danger of being contaminated. After several meetings citizens petitioned the city to:

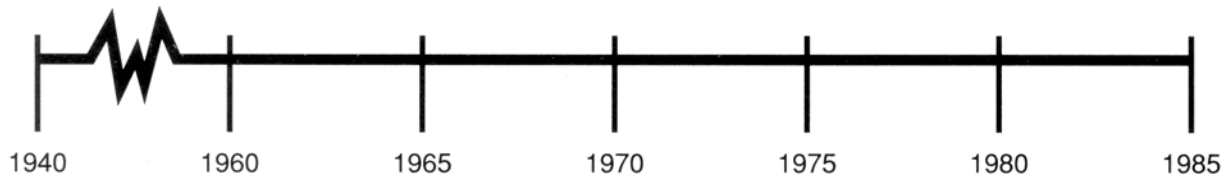
- 1) Guarantee that the VOC problem be solved before the contamination spread to the new community well.
- 2) Guarantee alternate sources of water for contaminated wells.
- 3) Guarantee purchase of affected properties to maintain property values if the contamination problem cannot be solved.



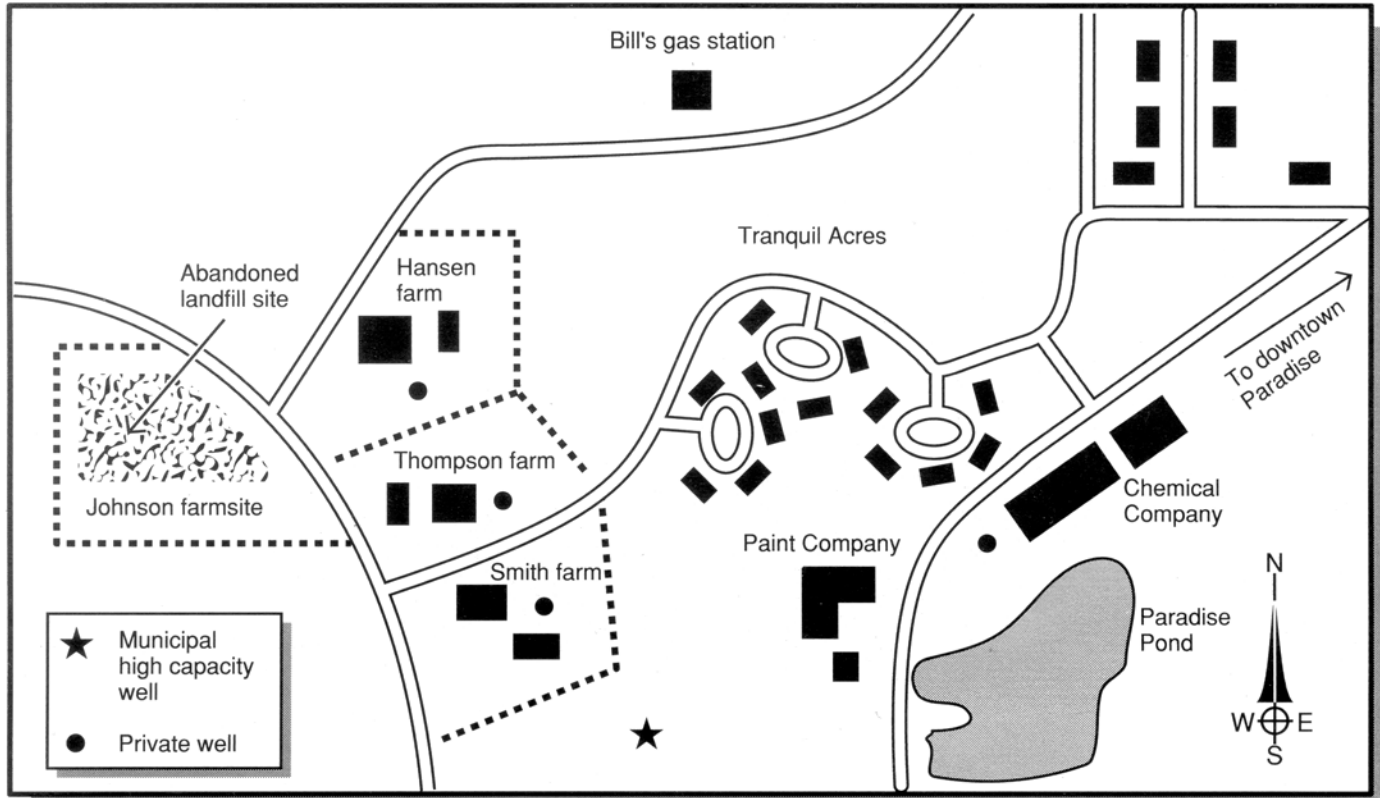
In August 1984, city council members determined that monitoring, testing and clean up could cost up to 3 million dollars. They have hired your company, the Contamination Busters, to help solve their groundwater problem before the community well is affected. Based on what you know about groundwater and the information you have been given, complete the following report sheet for the city council.

1. Place letters representing the following events on the timeline below:

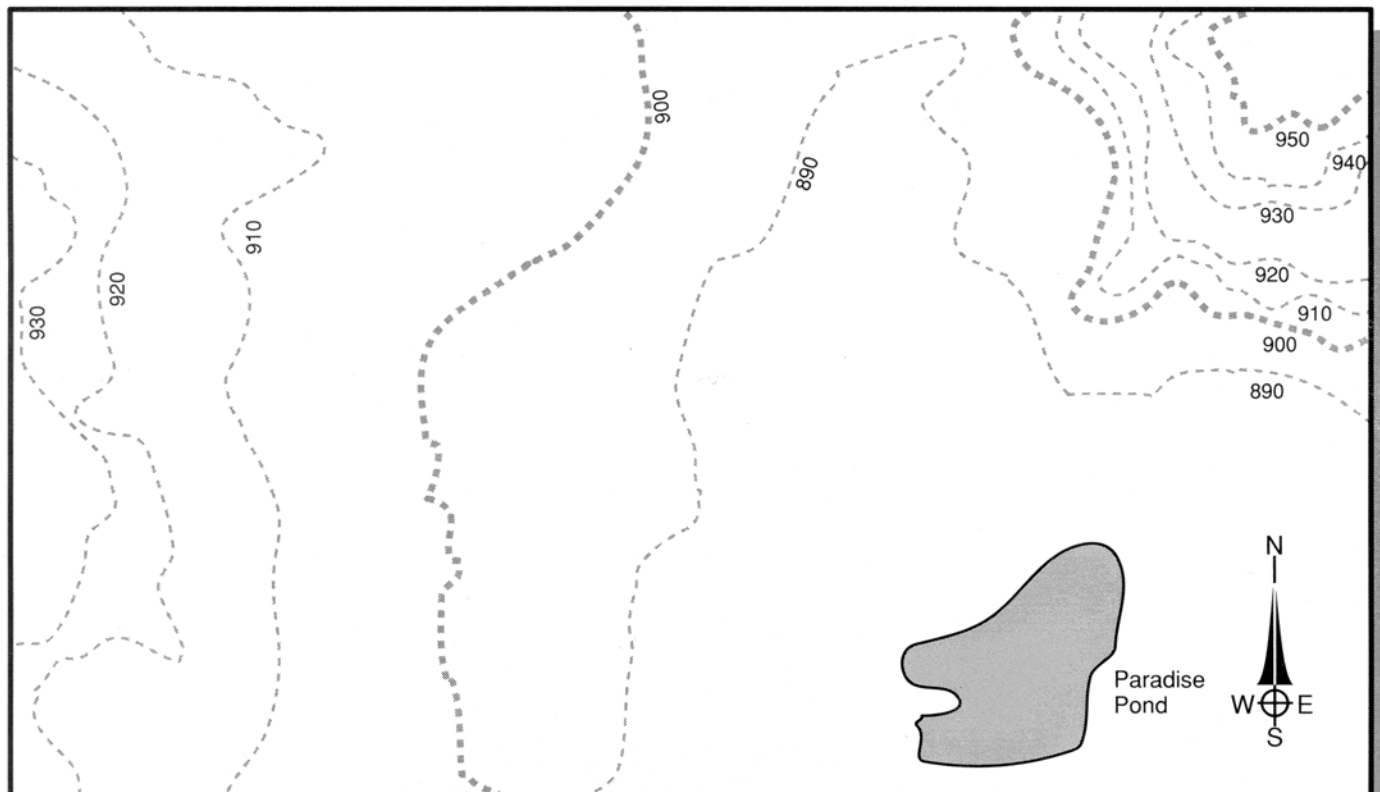
- A — Tranquil Acres is developed
- B — landfill is constructed
- C — citizens form action group
- D — landfill is covered
- E — Smiths contact health department
- F — local industries are built
- G — city council decides to take action
- H — high capacity well begins pumping
- I — Bill's gas station opens
- J — Hansens contact health department



2. Based on the topography of the Paradise area, draw an arrow on the map "B" showing the general direction of groundwater flow.



Map A



Map B



3. Complete the following tables.

Well	Parts per Billion Toluene				
	June 1983	February 1984	April 1984	May 1984	June 1984
Hansen's farm					
Thompson's farm					
Smith's farm					
Paint Company					
High capacity well					

Well	Parts per Billion Benzene				
	June 1983	February 1984	April 1984	May 1984	June 1984
Hansen's farm					
Thompson's farm					
Smith's farm					
Paint Company					
High capacity well					

4. Circle all VOC levels on the tables above that exceed Health Advisory Limits or Maximum Contaminant Levels.

5. Based on the information you have gathered, what is the source of VOC contamination?

6. With a **Red** pencil place X's on map "A" in places where you'd like to put monitoring wells to confirm the source of contamination.

7. Using the information on the data tables above, outline the plume of contamination before the high capacity well was built with a **blue** pencil. With a **green** pencil, outline the plume of contamination after the high capacity well was began pumping. Why did the plume change?



How Much is a Part per Billion? activity sheet

Many water quality standards are measured in parts per million, parts per billion, or even parts per trillion of pollutant in a given quantity of water. Regardless of what is being measured, ppm, ppb, ppt mean that there is one part of something in a million, billion or trillion parts of something else. The following table will help you understand this concept:

Unit	ppm	ppb	1 ppt
length	1 inch in 16 miles	1 inch in 16,000 miles	1 inch in 16,000,000 miles (a 6 inch leap on a journey to the sun!)
time	1 minute in 2 years	1 minute in 32 year	1 minute in 320 centuries
money	1 cent in \$10,000	1cent in \$10,000,000	1 cent in \$10,000,000,000

A part per billion doesn't seem like very much. But consider the amount of material that would be involved in all the water the Los Angeles area uses in a year (3,000,000 acre feet) if these contaminants were present at the following levels:

Substance	1 part per billion in the water Los Angeles uses in a year would be enough to:
lead	make 1,000,000 bullets
chromium	plate 50,000 car bumpers
mercury	fill 4,000,000 thermometers
herbicide	kill all the dandelions in 100,000 lawns
insecticide	fill 5,000,000 aerosol cans of bug killer
gold	support 50 average families for eternity

Very small amounts of some pollutants can harm people and wildlife.

For example:

ppm	ppb	ppt
If there is 1 ppm oil in the water, 1/2 of the Dungeness crab will be killed	At levels of 20 ppd Hg in their blood, humans show symptoms of mercury poisoning	Brook trout cannot grow properly or reproduce at levels of toxaphene over 39 ppt.

Maybe a part per billion isn't so small after all!

Adapted from C. Revelle and P. Revelle, *The Environment*, 1988, pp.112-114, Boston: Jones and Bartlett Publishers, Inc.